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Optimizing global force management for Special Operations Forces

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THESIS

OPTIMIZING GLOBAL FORCE MANAGEMENT FOR SPECIAL OPERATIONS FORCES

by

Emily A. LaCaille

December 2016

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In light of increasing Special Operations Forces (SOF) mission requirements, United States Special Operations Command (USSOCOM) requires a tool for planning to fulfill force requirements of the most valuable missions while sustaining SOF capabilities within operations tempo constraints. Currently, USSOCOM stakeholders attend numerous meetings throughout the year to qualitatively determine which missions will be fulfilled with available units. For this cycle, USSOCOM has implemented an additional meeting to create a prioritized mission list from which analysts can allocate units.

This research introduces an optimization model to provide USSOCOM with insights to improve the current process for the allocation of unit resources to annual mission priorities by using a multi-period inventory model to optimize the allocation of units to missions by maximizing mission prioritization subject to unit availability. This model automates the allocation process and provides analysts a tool that efficiently analyzes unit to mission allocations. With an analyst's interpretation of our model, the stakeholders and decision makers are equipped with the knowledge of specific resource limitations prohibiting the fulfillment of missions to make better-informed decisions on which missions requiring the same limited resources to fulfill, or on how to obtain the necessary resources.

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OPTIMIZING GLOBAL FORCE MANAGEMENT FOR SPECIAL OPERATIONS FORCES

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ABSTRACT

In light of increasing Special Operations Forces (SOF) mission requirements, United States Special Operations Command (USSOCOM) requires a tool for planning to fulfill force requirements of the most valuable missions while sustaining SOF capabilities within operations tempo constraints. Currently, USSOCOM stakeholders attend numerous meetings throughout the year to qualitatively determine which missions will be fulfilled with available units. For this cycle, USSOCOM has implemented an additional meeting to create a prioritized mission list from which analysts can allocate units.

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LIST OF ACRONYMS AND ABBREVIATIONS

CJCS	Chairman of the Joint Chiefs of Staff
COCOM	Combatant Command
GAMS	General Algebraic Modeling System
GFM	Global Force Management
SecDef	Secretary of Defense
SOF	Special Operations Forces
TSOC	Theater Special Operations Command
USSOCOM	United States Special Operations Command

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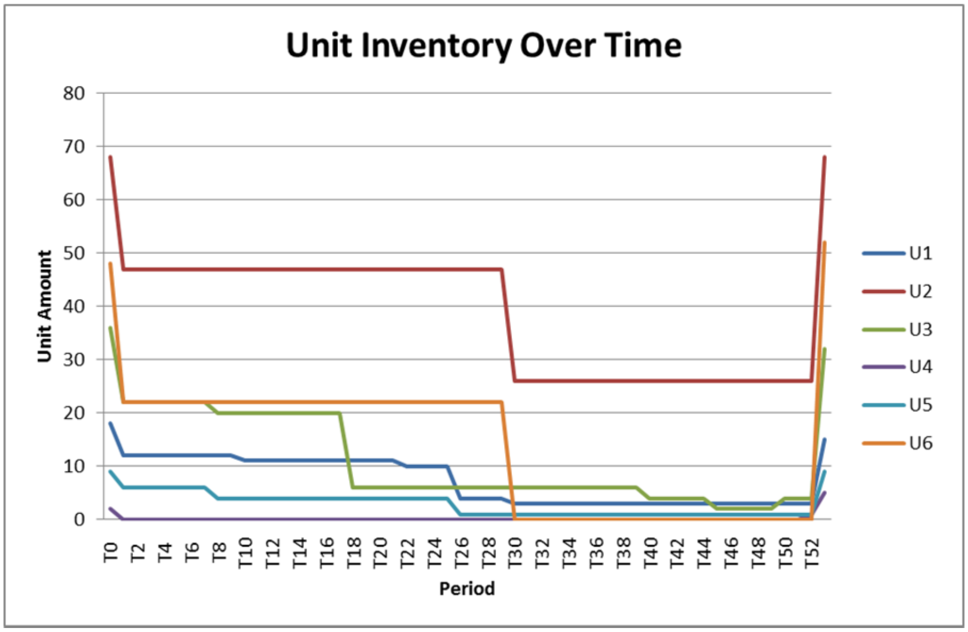
EXECUTIVE SUMMARY

Demands for Special Operations Forces (SOF) have significantly risen as conflicts in the current global environment increasingly "fall outside of the traditional peace-or-war construct" and therefore require a non-traditional response (Votel 2015). United States Special Operations Command (USSOCOM) needs to improve current processes to efficiently allocate forces to maximize mission fulfillment while sustaining SOF capabilities. The USSOCOM J3 directorate is responsible for the Global Force Management (GFM) allocation of units for the fulfillment of Special Operations Forces (SOF) missions. The USSOCOM J3 conducts an annual meeting with the Combatant Commands (COCOMs) to establish mission priorities and associated unit requirements. Currently, the J32 then allocates units to these missions using units available in the Special Operations Force Generator. The final product is an Excel spreadsheet referred to as the Global Force Management Allocation Plan. This repetitive annual process is currently done by hand.

Beginning this year in planning for the next fiscal year, starting October 1, 2017, USSOCOM J3 is attempting to create a mission prioritization list, which is ideal for use in an optimization model. This research develops an optimization model with a prioritized mission list to allocate available units to fulfill the most valuable portfolio of missions. We generate the data framework necessary for the model given a portion of this mission prioritization list as well as the relevant portion of the current Special Operations Force Generator. We create notional data to run an unclassified model as a proof of principle and for the purpose of thesis completion.

We run our model on a small dataset similar in size and scope to a small subset of classified data provided by USSOCOM. The model solves for the optimal allocation of units to missions given mission priorities. We create outputs in our model to build a mission allocation report and a unit-inventory sensitivity report that are easy to interpret by analysts and non-analysts alike. The mission allocation report lists the missions that are fulfilled by the optimal solution of our model. An analyst can use the unit-inventory sensitivity report to create and update a chart of unit inventory throughout the year

(Figure A). We run a small subset of missions to explore the complexity to the problem. Using the output of our reports, we conduct what-if analysis on our model's optimal solution result to answer the most likely decision maker question when a mission is unfulfilled.



Of interest to fulfilling requirements for mission M1, we see that the unit U4 goes to zero inventory in T26 and the unit U6 goes to only two units available in T30.

Figure A. Small Dataset Unit Inventory Sensitivity Results

In our what-if analysis, we first identify why the mission in question is left unfulfilled in the initial optimal solution. We find that multiple lesser-ranked missions are fulfilled with the same unit requirements as the higher ranked mission left unfulfilled. Due in part to the ordinal ranking of the mission prioritization list, the combined value of fulfilling these multiple missions displaces the value of the higher unfulfilled mission. We then analyze what it will take to fulfill the unfulfilled missions, by adding new units where required according to the unit inventory sensitivity report. We also run our model on a large dataset with similar size and scope to the full mission set of USSOCOM to demonstrate our model capability.

With our model, it is now possible to quickly identify what specific limitations in resources are causing conflicts between mission fulfillments. The decision maker is enabled, by an analyst interpretation of our model output, to make more informed decisions about which missions to fulfill over other missions requiring the same limited resources. Stakeholders and decision makers are also now equipped with the results of our model to request additional resources necessary for mission fulfillment, or to make decisions to amend unit reset timelines to make the necessary resources available.

With a comparison between our what-if analysis on the small subset of data and the results of our large USSOCOM-sized dataset, we estimate an analyst equipped with our model can answer what-if questions of stakeholders in about one full week of work. This feat - made possible by our model - was not previously plausible in the current processes of USSOCOM. With our model, we provide USSOCOM with a powerful tool to automate the allocation process for Global Force Management. This tool empowers the analyst to conduct timely what-if analysis and easily develop alternate courses of action.

REFERENCE

Votel, JL (2015) Posture Statement of General Joseph L. Votel, U.S. Army Commander, United States Special Operations Command, before the Senate Armed Services Committee, Washington, DC.

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I. INTRODUCTION

A. SPECIAL OPERATIONS AND USSOCOM BACKGROUND

Special operations include special reconnaissance, unconventional warfare, counter-terrorism, counterinsurgency, counter-proliferation of weapons of mass destruction, foreign internal defense, foreign humanitarian assistance, civil affairs, and military information support operations (Joint Chiefs of Staff 2014). Special operations are employable in politically and diplomatically sensitive environments, as well as in hostile or denied areas that require one or more of the following conditions: a covert nature, low visibility, time-sensitivity, indigenous forces cooperation, regional orientation and cultural expertise, or a higher degree of risk (Joint Chiefs of Staff 2014). It is the responsibility of the United States Special Operation Command (USSOCOM) to train and task Special Operations Forces (SOF) to perform these critical missions.

USSOCOM oversees eight sub-unified commands; these include seven Theater Special Operations Commands (TSOCs) and the Joint Special Operations Command that perform broad, continuous missions requiring SOF capabilities (Joint Chiefs of Staff 2014). Additionally, USSOCOM has four service components: the U.S. Army Special Operations Command, Marine Corps Forces Special Operations Command, Naval Special Warfare Command, and Air Force Special Operations Command. USSOCOM faces an incredible challenge in the tasking of SOF to these high demand complex missions across all eight sub-unified commands.

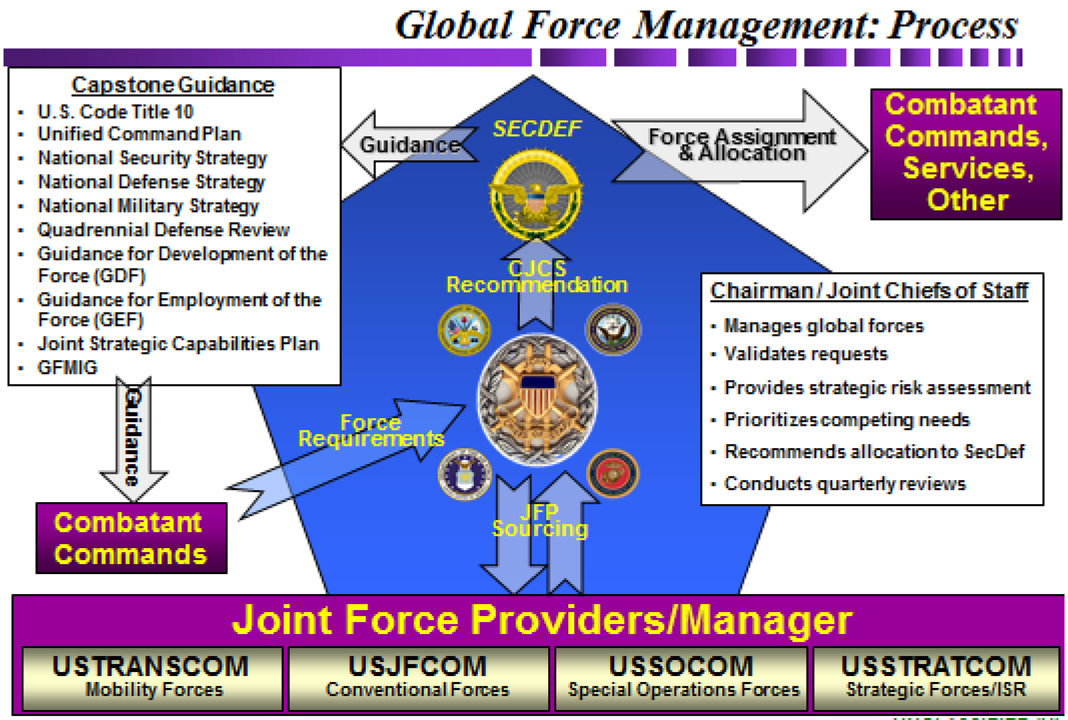
B. INCREASING DEMANDS FOR SPECIAL OPERATIONS

Demands for Special Operations Forces (SOF) have significantly risen as conflicts in the current global environment increasingly “fall outside of the traditional peace-or-war construct” and therefore require a non-traditional response (Votel 2015). USSOCOM has a portfolio of options to deal with these increasingly complex challenges, with over 69,000 personnel deployed to more than 80 different countries worldwide (Votel 2015). From fiscal years 2001 to 2014, the average weekly deployments of SOF personnel increased from about 2900 to 7200, which represents a 148% increase in deployments (Pendleton 2015). Over the last 14 years, an increasing operations tempo has decreased the predictability of deployments (Votel 2015). In that same timeframe, the average SOF service member deployed as many as 10 times, frequently with less than 12 months at home between deployments (Votel 2015).

The current force allocation process, discussed in greater detail in the next section, provides for the validation of force requests but does not consider whether conventional forces could perform the same activities conducted by SOF (Pendleton 2015). Until the demands can be better distributed across all forces, special operations and conventional alike, the tempo of SOF deployments will remain high (Pendleton 2015). Predictability of personnel tempo is a key component to building the resiliency of SOF forces and their families, and, in turn, the preservation of SOF capabilities (Votel 2015). Distributing demands among conventional forces and SOF is outside the scope of our thesis, but is relevant to future improvement of the problem facing USSOCOM. Within the scope of this thesis, we focus on the need of USSOCOM to efficiently allocate SOF to maximize mission fulfillment while sustaining SOF capabilities by developing a model to optimally allocate units to missions.

C. OVERVIEW OF USSOCOM GLOBAL FORCE MANAGEMENT PROCESS

USSOCOM currently conducts force allocation within the annual Global Force Management (GFM) process. This process begins when the president documents his direction through the Unified Command Plan (GFM Division 2016). The Unified Command Plan assigns missions, responsibilities, forces, and capabilities to combatant commanders (COCOMs) (GFM Division 2016). Then the Global Force Management Implementation Guidance, issued under the authority of the Secretary of Defense (SecDef), details the allocation of forces (GFM Division 2016). Within this allocation authority, forces assigned to a COCOM may be transferred to another COCOM for employment (GFM Division 2016). The Chairman of the Joint Chiefs of Staff (CJCS) prepares strategic plans and apportions forces to combatant commands based on SecDef’s contingency planning guidance (GFM Division 2016) (Figure 1).



The image depicts the allocation planning process as follows: 1) SecDef guidance to COCOMs, 2) COCOMs develop requests for rotational forces, 3) CJCS validates requests, 4) Joint Force Providers develop sourcing solutions, 5) CJCS recommends a final solution to the SecDef 6) SecDef makes a decision to allocate SOF and 7) CJCS publishes Deployment Order for COCOMs. The final step 7) is the SecDef's Deployment Order wherein orders are established for SOF units designated to missions by the GFM Allocation Plan.

Figure 1. USSOCOM GFM Process. Source: Global Force Management Division, J3 USSOCOM (2015).

Initially within the GFM allocation planning process, the GFM Implementation Guidance provides high-level aspirational objectives to support the president's direction. USSOCOM then identifies attributes that support those objectives to evaluate each mission and determine their relative value to create a prioritized mission list. Currently, USSOCOM conducts annual meetings to establish an ordinal list of prioritized missions for the next fiscal year. Allocation of available forces is then directed by fulfilling the requests for forces of missions based on their rank order in the prioritized mission list. USSOCOM accounts for the availability of forces in the special operations force generator. The special operations force generator is a process to make forces ready and available for deployment. Inherent in the special operations force generator, each individual unit is listed with the date it will be available. Following the issuance of the prioritized mission list, USSOCOM scrutinizes the special operations force generator for an inventory of available units and allocates units to missions by mission priority by hand in excel. This produces the current GFM Allocation Process utilized to assign units to missions. The GFM Allocation Process currently takes one staff member about three weeks or about 80 man hours. This process is not quickly replicable to identify, analyze and pursue alternate courses of action.

D. THESIS CONTRIBUTION

Starting with the current GFM Allocation Process, we create a decision support tool, which prescribes solutions for the GFM Allocation Process using a dataset similar in scope to USSOCOM's classified data. The GFM planning tool we develop provides USSOCOM a way to automate and inform the GFM Allocation Process for future mission planning. Additionally, because our tool finds the optimal allocation of units to missions, it also enables a GFM analyst to pursue alternative courses of action in a real-time fashion as the decision maker or stakeholders asks multiple and follow-on "what if" type questions. We hypothesize that in just a week's time an analyst can answer all "what-if" questions, which previously would not be possible, in any reasonable amount of time, without the optimization model developed in this thesis.

II. LITERATURE REVIEW

This chapter provides a brief discussion of literature relevant to this thesis. First, a review of literature on value-focused thinking captures the approach USSOCOM attempts to use for developing the objective function. Second, a review of literature relating to the generalized assignment problem provides a foundation for building the multi-period assignment problem. Finally, a discussion of relevant models facilitates the model construction with the objective function and constraints.

A. VALUE-BASED DECISION MAKING

A short review of relevant literature on the concept of value-based decision-making and additive value models follows. In *Decisions with Multiple Objectives*, Keeney and Raiffa (1993) describe the use of Multiple Attribute Utility Theory to create superior consequences by creating better situations to foster decision-making with better alternatives. They emphasize focusing early on in the decision making process to define fundamental objectives that represent desired outcomes. These fundamental objectives then are easily broken up to set the conditions for forming an additive value model. Keeney (2002) popularized the use of "value functions" by using Multiple Attribute Utility Theory in a decision context where "utility" preference is replaced by "value" preference.

Parnell (2005) and Ewing et al. (2006) encourages the use of multiple-objective decision analysis, i.e., "Value Focused Thinking," to determine the best alternatives when there are multiple, conflicting objectives and significant uncertainties. Both articles describe the importance of getting stakeholders' qualitative input in developing the objective hierarchy and attributes, and in doing so obtain stakeholder ownership of the analysis. Ewing (2006) in particular stresses the importance of using "measurable" value functions when using multiple-objective decision analysis to determine the objective function coefficients for an optimization model.

In general, the multi-objective decision analysis technique described above will result in a prioritized list of alternatives. When the number of alternatives under consideration is a “small” countable set then these techniques alone are usually sufficient in finding Pareto optimal solutions to multiple-objective decision problems (Lin 1975). However, when the number of alternatives under consideration is large, e.g., tens of thousands possible unit to mission combinations, then an optimization technique is required to prescribe the best solutions. As described in Ewing et al. (2006), one approach is to use multiple-objective decision analysis to determine the objective function coefficients for the optimization model’s objective function.

B. THE ASSIGNMENT PROBLEM

Ahuja et al. (1993) discuss the assignment problem in *Network Flows: Theory, Algorithms, and Applications*. They describe the assignment problem as a special type of maximum flow problem that consists of two sets and all possible pairs representing possible assignments. In this thesis, those sets are units and missions, and those pairs are all possible assignments of units to missions. The general assignment problem is similar to the model that this problem.

Rardin (1998) addresses assignment problems as an important class of network flow models. He defines the issue assignment problems address as the optimal pairing of objects from two distinct types: jobs to machines or, as in this thesis, units to missions. The standard model for an assignment problem assigns or matches each object of each set exactly once (Rardin 1998). Figure 2 portrays the general single-period assignment problem formulation.

$$\max \quad z = \sum_{u,m} x_{u,m} \qquad (1)$$

$$\sum_{m} x_{u,m} = 1 \ \forall u \qquad (2)$$

$$\sum_{u} x_{u,m} = 1 \ \forall m \qquad (3)$$

$$x_{u,m} = 0 \ \text{or} \ 1 \ \forall u,m \qquad (4)$$

The objective function (1) seeks to maximize the pairs of u to m. Equation (2) forces all u to be assigned and equation (3) forces all m to be assigned. Then, if a u and m pair exists the decision variables ($x_{u,m}$) are set equal to 1 and if u and m are not paired the decision variables are set equal to zero in equation (4).

Figure 2. The Single-Period Assignment Problem Model.

The single period assignment problem lacks the aspect of time required by the problem presented in this thesis. There also is not a strict one-to-one ratio of units to missions. In USSOCOM's unit-to-mission assignment problem, missions also demand units at different start times and over varying periods. Our problem, then, is not strictly an assignment problem. We next look to relevant linear programming models to develop a model for USSOCOM's problem.

C. RELEVANT LINEAR PROGRAMMING MODELS

The USSOCOM problem suggests a multi-period assignment type of problem with several side constraints. A review of the literature did not uncover an applicable model. We follow with a short review of relevant models, which share characteristics of the mixed integer linear program we develop and implement to analyze the USSOCOM unit to mission assignment problem.

DeGregory (2007) develops a binary integer program to optimally allocate the force protection resources to a set of planned logistical convoys. As a resource allocation problem, this has some relevancy to unit to mission allocation for this thesis.

Aronson and Elnidani (1986) develop an integer multi-commodity, multi-period assignment problem formulation to assign people to jobs over several periods. They use a linear programming relaxation of the multi-commodity network flow problem and develop a branch and bound algorithm. To maintain the network structure they ensure a one-to-one ratio of people to jobs in any given time period by creating dummy jobs or people, as necessary, with no associated cost for assigning a dummy variable.

Silva (2009) develops an integer linear program to allocate ships to missions to create an optimal employment schedule. Silva's model incorporates costs in the form of distances of ships to missions, or a ship's current region in relation to the region in which the mission is to occur. Though similar to this ship to mission construct, this unit to mission thesis does not account for regional or distance associated costs when assigning units to missions.

We will create a linear model using the prioritized mission list and constraints based on unit to mission mapping, unit availability timelines, and mission fulfillment timelines. The model will span multiple periods, will assume whole unit assignments, and will therefore, be a multi-period linear program with integer values.

III. MODEL FORMULATION

A. MULTI-PERIOD INVENTORY MODEL

We develop a multi-period inventory linear programming model to allocate units to missions to maximize the overall mission fulfillment given unit availability and reset timeline constraints. The objective is to assign units to as many of the most valuable missions possible. The primary modeling assumptions, limitations and restrictions, and other modeling constraints follow.

1. Assumptions

This model uses notional and therefore unclassified data similar in scope to the actual classified data provided by USSOCOM. The model uses an ordinal prioritized mission list and associated requests for forces, in the same format as USSOCOM. We assume mission requirement frequency to be no more than weekly and therefore, depict 52 periods for 52 weeks in a fiscal year for our modeling purposes. We translate into these periods the desired start and end dates of requests for forces, as well as all unit availability dates, and reset timelines for each type of unit.

Many mission requirements exceed the availability dates of the specified unit. For these instances we assume the requirement is broken into mission requirement segments that are fulfilled by multiple units one after another. Mission requirements may also request more than one type of unit. We assume a further break down into mission requirement segments to assign different unit type segments in addition to different time segments. We discuss these mission requirement segments in more detail in Chapter IV.

2. Limitations and Restrictions

The model is constrained by the initial unit inventory and individual unit availability and reset timelines. The first period receives all initially available unit inventory. Any unit utilized for mission requirements is removed from the available unit inventory at the end of the period it is requested in. The utilized unit then remains out of inventory until it has completed the mission requirement, subject to the individual unit type's availability timeline, as well as the unit's reset timeline.

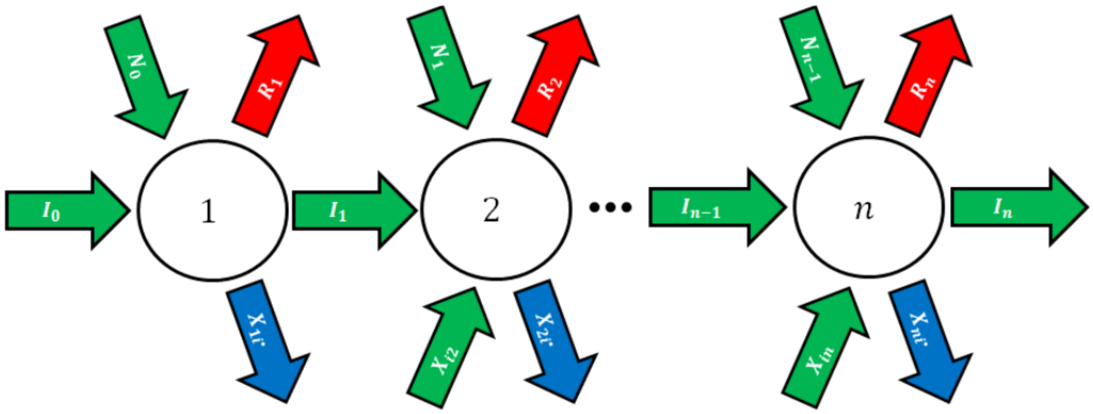
We are also limited by the prioritized mission list given by USSOCOM. This is an ordinal list that values missions as 1, 2, 3, and so on. Ordinal values mean that the top prioritized mission is equally valued over the second as the second is to the third. In reality, the top mission may be ten times more valuable than the next. This is may be improved in the future by using measurable value functions as discussed in Ewing et al. (2006) while establishing mission prioritizations.

3. Other Modeling Considerations

Additionally, we consider any units that may be removed from inventory for any reason, i.e., they are retired from service. Removed units leave at the end of each period and no longer exist in the following periods. We also consider any new units that did not previously exist and are stood up for whatever reason. These new units are available at the beginning of any period in which they are stood up.

4. Model Depiction as a Network

We demonstrate the essential flow of the problem in Figure 2. We define unit inventory, I, as the amount of a unit type, which is available for assignment during a given period. For example, the initial inventory, I_0, at the beginning of period 1 must equal the number of that unit type assigned to a mission by the end of period 1, $X_{t,tp}$, where t is the current period and tp is the end of the assignment period for that unit plus any units not assigned by the end of period 1, I_1. The N_0 and R_1 parameters of Figure 3 represent the addition of new units or removal of existing units, respectively, during period 1. This leads us to the formulation of our model, which expands the unit inventory flow model to multiple units, multiple missions and mission segments; wherein a mission segment differs in both unit type and time period requirements. Mission segments are further discussed in Chapter IV.



This figure is a representation of the requirements for a single mission with only one unit type. All green arrows represent unit flow into the beginning of each period, where I is all units in inventory, N is new units, and X are units completing mission requirements and reset timelines. Red and blue arrows represent units taken out of unit inventory at the end of each period, where R is units removed permanently, and X is units utilized for mission requirements. Each variable subscript indicates the period from which it originates, where I_0 is initial inventory from before period 1, in other words from period 0. For each X subscript the first number indicates the period X is initially used in and the second indicates the period X is available again for inventory, for example X_{i2} indicates all X now available in period 2 from any period i that they were initially used in. All in-flows must equal out-flows for each period, for example in period 1: I_0 plus N_0 must equal R_1 plus I_1 plus X_{1i*}.

Figure 3. Unit Inventory Flow

B. MODEL FORMULATION

1. Indices

u	Units
m	Missions
s	Mission Segment Requirements
t	Period a requirement begins in
tp	Period a requirement ends in

2. Sets

MT	Mission Segments
$UMS \subseteq MT$	Subset of Unit Mission begin times

3. Parameters

$value_m$	Mission value
$unitReq_{u,m,s,t,tp}$	Unit request for mission segment beginning at period *t* and ending at period *tp*
$numS_m$	Number of segments for Mission m
$unitAvail_u$	Number of unit type *u* available at the end of period *0*
$newUnits_{u,t}$	New units u at the beginning of period t
$removeUnits_{u,t}$	Remove units u at the beginning of period t
pen	Penalty on semi-continuous variable

4. Integer Variables

Z	Objective function value
$X_{u,m,s,t,tp}$	Number of units of type *u* allocated to mission *m* segment *s* from period *t* to period *tp*
$I_{u,t}$	Inventory of units of type *u* available for assignment in the end of period *t*

5. Binary Variables

$Y_{u,m,s}$	= 1 if unit *u* assigned to mission *m* segment *s*, zero otherwise
W_m	= 1 if all segments *s* of mission *m* are fulfilled, zero otherwise

6. Formulation

$$MAX\ \ z = \sum_m value_m W_m - \sum_{(u,m,s)\in UMS} pen * Y_{u,m,s} \qquad (1)$$

subject to

$$unitAvail_u = I_{u,1} + \sum_{(m,s,tp)\in MT \cap\ tp>t} X_{u,m,s,1,tp} \qquad \forall u \qquad (2)$$

$$I_{u,t-1} + newUnits_{u,t} + \sum_{(m,s,tp)\in MT \cap tp<t} X_{u,m,s,tp,t} =$$

$$I_{u,t} + removeUnits_{u,t} + \sum_{(m,s,tp)\in MT \cap tp>t} X_{u,m,s,t,tp} \qquad \forall u, t>1 \qquad (3)$$

$$X_{u,m,s,t,tp} = unitReq_{u,m,s,t,tp} * Y_{u,m,s} \qquad \forall (u,m,s,t,tp)\in MT \qquad (4)$$

$$\sum_{(u,s)\in UMS} Y_{u,m,s} \geq numS_m * W_m \qquad \forall m \qquad (5)$$

7. Discussion

The objective function (1) seeks to maximize the value of missions fulfilled. A small penalty is extracted for each mission segment selected to remove unused segments from the solution. Constraint (2) sets up the initial balance of flow for inventory of units in period T1. Constraint (3) sets up the balance of flow for inventory in all periods following T1, for each unit type. Constraint (4) enforces the unit to mission assignment if possible by making the assignment variable, *X*, semi-continuous and ensures units are removed from available inventory whenever assigned a mission segment. Constraint (5) ensures that the entire mission is fulfilled only when all of the mission segment requirements are fulfilled. This is accomplished when the individual mission segments selected through the Y variable equal the number of segments in a given mission.

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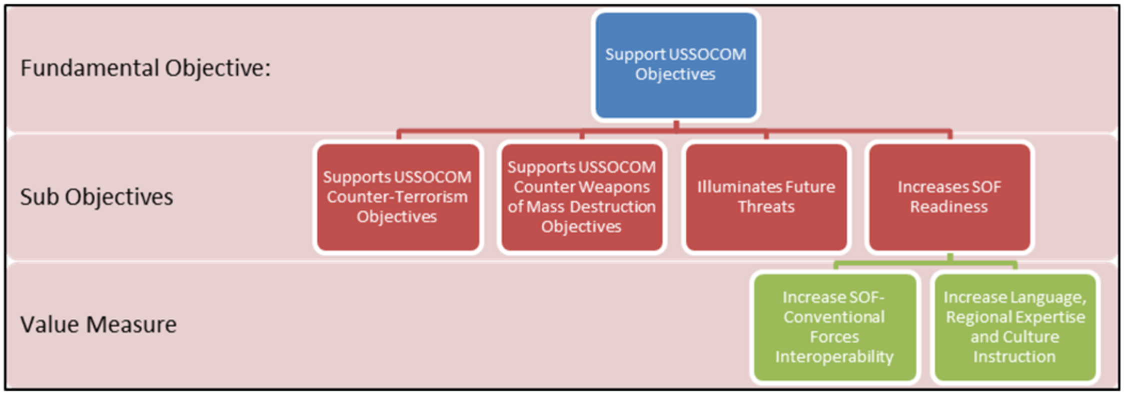
IV. ANALYSIS

A. DATA FRAMEWORK

The data for the objective function of our model is the mission prioritization list as created by USSOCOM. The data necessary for our model constraints is available from two processes currently maintained by USSOCOM. Mission data requirements for our model are obtainable from the annual GFM meeting between USSOCOM J3 and COCOM commanders. In addition, unit inventory requirements exist in the Special Operations Forces Generation process. The USSOCOM assumptions, planning factors, rules, and guidance depicts unit availability and reset timelines, which are unclassified. At the direction of USSOCOM, we work on the small subset of the data given to us and transform it to unclassified data. Figures 4, 5, and 6 depict the relevant mission and unit data requirements to run our model, as truncated and translated from USSOCOM’s current spreadsheet tracker formats.

1. Objective Function Data Requirements

For the first time ever, USSOCOM developed a mission attribute value hierarchy to fulfill overarching goals during the annual Global Force Management planning for fiscal year 2017 SOF employment (Bradley 2016). This is a first step toward employing an optimization methodology, described in Ewing et al. (2006) by developing a transparent and defendable mission prioritization scheme. USSOCOM attempts to identify the fundamental objectives, sub-objectives, and associated attributes with the qualitative input of the TSOCs and other stakeholders (Bradley 2016). Figure 4 displays a portion of the mission attribute value hierarchy developed by USSOCOM.



This figure displays a small portion of the mission attribute value hierarchy developed by USSOCOM in fiscal year 2017 GFM planning. Overarching goals are identified in the first tier as fundamental objectives. All goals that support the fundamental objective are identified in the second tier as sub objectives. Finally, all attributes that contribute to each sub objective are identified in the third tier as value measures. To complete the process, stakeholders will identify the attributes that each mission contributes too and then an overall value would be calculated for each mission.

Figure 4. Mission Attribute Value Hierarchy. Adapted from GFM Division, J3 USSOCOM (2015).

USSOCOM has begun the process of structuring the mission attribute value hierarchy (Figure 4), but has not yet created value functions for these attributes as discussed in multiple attribute utility theory in Keeney (2002). Additionally, USSOCOM also has not begun to identify how each mission contributes or not to each attribute. USSOCOM will be able to create a measurable mission prioritization list once it is creates value functions for these attributes, and identifies how each mission contributes to these attributes. USSOCOM's goal should be a measurable prioritization mission list ranked by interval parameters versus ordinal parameters.

USSOCOM has not yet developed value functions. For this research, we use the provided ordinal one-to-n mission prioritization list. It is important to note here our model is designed to work with any assigned mission value, including future value functions. The prioritization list we use here was created during the annual GFM meeting with the TSOCs. Figure 7 displays an adapted version of the data provided by USSOCOM, wherein each mission is named “M1,” “M2” and so on for our unclassified dataset. We also simplify our unclassified data for analysis purposes and give the missions a corresponding priority of 1 or first priority for M1, 2 for M2, and so on through the total number of missions.

We transform the dataset given to us to input into our optimization model to keep this work unclassified and to replicate a similar size and scope of the classified data subset. With an ordinal prioritization, and therefore no measurable distance between mission values, the values of the missions are essentially a reverse order of the mission prioritization. Since the ordinal rankings represent the objective function coefficients for the optimization model, M1 is given the highest value of 20 down to M20 that receives a value of 1. Now that we have defined the data assigned to the objective function coefficients, we next introduce the remaining data definitions beginning with the asset inventory data.

2. Unit Type Inventory Data

We define unit type inventory data as the initial unit type inventory, new and removed unit types, and unit type availability and reset timelines. In this analysis we are interested in assigning a "unit type," rather than a particular unit, to a mission, although this model can be generalized with little difficulty to do the latter. The available dates of units of a particular type are currently in a DD-MMM-YY format, which we convert to a period from T1-T52 to represent the weeks in a fiscal year. For this model, we also extend the unit requirement to include the reset timeline, for example a unit type of U1 employed for 180 days in a mission will additionally reset for another 180 days and is thus unavailable for a 360 day period. The quantity of units of a particular type may also be newly introduced or permanently removed from inventory during the fiscal year. These new or removed units go into or come out of inventory at the beginning of the period they are stood up or retired. Figure 5 depicts a spreadsheet with our translation of relevant data from SOF generation for unit inventory, including new and removed units. Figure 6 depicts our translation of planning factors, rules and assumptions for unit type availability, and reset timelines.

Unit Availability

Unit Type	Available Date	Unavailable Date
U1	1-Oct-16	1-Oct-36
..	1-Oct-16	1-Feb-17
U1	1-Jun-17	1-Oct-36
U2	…	
…		
U2		
…		

Initial unit type inventory is indicated by any unit with an available date at the beginning of the fiscal year, i.e. 1-Oct-16. Newly added units are any unit with an available date past the start of the fiscal year as in the highlight 1-Jun-17. Removed units include those with an unavailable date within the fiscal year as in the highlight 1-Feb-17. Units are unavailable for the mission requirement duration or their available days limit (whichever is shorter) plus their reset day requirement. Adapted from USSOCOM, SOF Generation (2016).

Figure 5. Initial Unit Inventory, New And Removed Units

	Rotation Rate	
Unit Type	Available Days	Reset Days
U1	180	180
U2	210	420
U3	120	360
…		

Each unit type is unavailable for the mission requirement duration or their available days limit (whichever is shorter) plus their reset day requirement. Adapted from USSOCOM, Planning Factors, Rules and Assumptions Guidance (2016).

Figure 6. Unit Availability and Reset Timelines

3. Mission Requirements Data

USSOCOM provided mission requirements corresponding to the missions in the prioritized mission list. Mission data requirements include each mission’s priority (discussed previously in section 1 of this chapter), request for forces (unit type request), and the required mission start and end date. The start and end dates are currently in a DD-MMM-YY format. For the purpose of our model, we convert this to a period from T1-T52, which depicts the weeks in a fiscal year. As discussed in the previous section, we convert the full mission names to “M1,” “M2,” and so on and the specific unit types to

"U1," "U2" and so on. We also conduct a count of each unit type available and include this as a "Unit Amount," i.e., the capacity of each unit type. Figure 7 depicts our translated version of the USSOCOM spreadsheet of mission priorities and requirements relevant to running our model.

Mission Requirements

Mission	Priority	Requested Start	Requested End	Unit Type	Unit Amount
M1	1	1-Dec-16	1-Jun-17	U1	2
	2	1-Nov-16	1-Jul-17	U2	3
	…				
	n	.	.	.	
M2	1	2-Feb-17	1-Feb-18	U3	4
	…				
	n	.	.	.	
…					
Mission n					

Missions are listed from M1 through the total number of missions (n) with their associated priority number 1 through n. Missions may have multiple requirements by different unit types. The start and end dates of each requirement are listed, as well as the unit type and the number of required units of that type. Adapted from J3 USSOCOM, GFM Mission Prioritization and Requirements (2016).

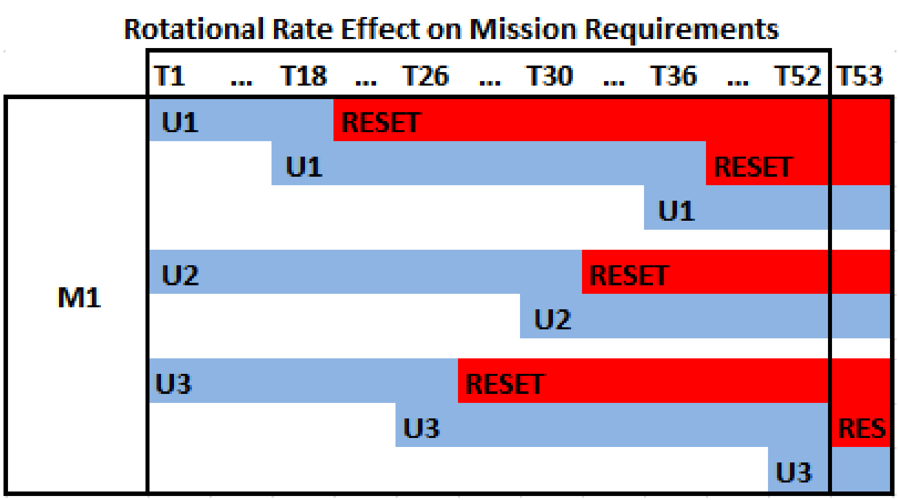
Figure 7. Mission Data Framework

Comparing the mission requirements data to the unit inventory data, we identify the necessity for breaking up mission requirements into mission requirement segments; wherein a mission that requires more than the availability timeline of a given unit is broken up into several mission requirement segments. We continue below in detailing the necessary data framework for our model by further discussing these mission requirement segments.

4. Mission Requirement Segments

In reviewing our unit inventory data and mission requirements data, we see a shortfall between the duration of some mission requirements and the timeline for which the unit required is available. To account for this we break mission requirements into segments by the availability timeline of the unit type requested. A detailed explanation of how this mission requirement segments work within our model follows.

Our model starting point begins with an initial inventory of available units at the start of a fiscal year denoted as T_0 or time period zero. Then 52 periods represent each week of the fiscal year and a 53rd time period accounts for a rolling time horizon. We account for mission request for forces timelines in these periods. Any unit requirement during a period is fulfilled or not, as optimally chosen by the model. When a unit is chosen to fulfill a mission requirement, it leaves the unit inventory for the duration of the requirement or the time length it is available for (whichever is shortest), plus the reset timeline of the individual unit type. Many mission requirements span the entire fiscal year, which exceeds the availability timeline of most unit types. This creates multiple requirement segments for missions with a 364-day timeline requesting a unit type that has, for example, a 120-day availability timeline. Now, one requirement becomes three 120-day and one 4-day requirements to fulfill a full year requirement. A mission may also require different types of units that may have different availability timelines. This splits what was one mission request for forces into multiple unit and timeline segment requirements. Figure 8 illustrates a mission with multiple unit type requests that have different unit availability and reset timelines.



M1 denotes a mission that has requirements for U1, U2, and U3 unit types over an entire fiscal year from T1 through T53. U1, U2 and U3 all have different availability timelines depicted in blue and reset timelines depicted in red. Each requirement that exceeds the unit availability timeline will require multiple units to fulfill it; therefore, each line depicts a different unit of each unit type in the figure.

Figure 8. Mission Requirement Segments

B. RESULTS AND ANALYSIS

In this section, the model is first run on a small dataset to demonstrate the model capabilities and how it contributes to an analyst's ability to answer the most likely "what-if" type questions from stakeholders. The model is then run on a larger dataset we believe is similar in scope and size to the actual USSOCOM classified mission set, to demonstrate it is capable of handling the problem faced by USSOCOM.

1. Small Dataset Results

We first run our model on a small dataset with similar scope to our classified data subset provided by USSOCOM. This dataset includes 20 missions with a total of 85 mission requirement segments based on unit types requested and the individual unit type's availability and reset timeline. Each mission has an average of 4 mission requirement segments, with at least 2 and a maximum of 12 mission requirement segments. Additionally, there are a total of 6 unit types required for these missions. A typical mission requests an average of 2 different unit types, with a minimum of one unit type requested and a maximum of 4 different unit types requested. Figure 9 displays a subset of the data as an example of what we use for mission requirements. This dataset also includes six unit types with initial inventory as well as any new or removed units within the fiscal year.

Unit	Mission	Segment	t	tp	Amount
U1	M1	A	T1	T52	4
U1	M1	B	T26	T53	4
U1	M1	C	T52	T53	4
U4	M1	D	T1	T52	1
U4	M1	E	T26	T53	1
U4	M1	F	T52	T53	1
U6	M1	G	T1	T53	3
U6	M1	H	T30	T53	3
U3	M1	I	T1	T36	3
U3	M1	J	T18	T52	5
U3	M1	K	T36	T53	5
U3	M1	L	T52	T53	5

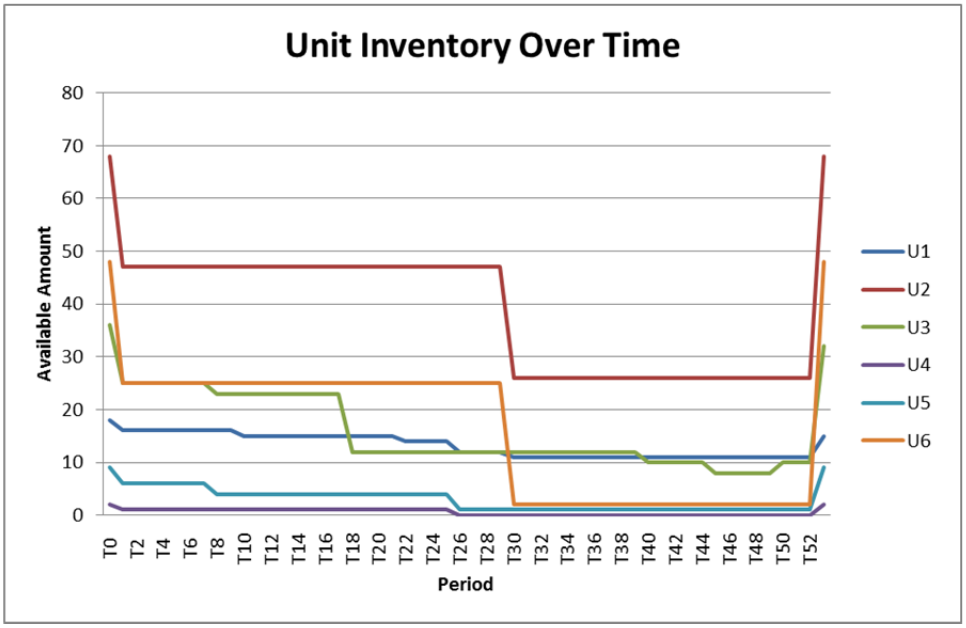
As an example of our mission requirement data, we display the requirements for the top priority mission "M1." The beginning of each segment requirement "t" and the end of each requirement "tp" includes both the time the unit is available and used for the mission requirement as well as the individual unit type's reset timeline. For example, U1 segment A comprises both the mission requirement from T1 through unit reset from T26 through T52. We then see U1 segment B continue the mission requirement following segment A in T26. We also see the many segments, A through L, required due to different unit types and timeline segments.

Figure 9. Mission Requirements Data

In running our model in the general algebraic modeling system (GAMS), the model's runtime statistics show us the size of the problem with 509 single variables to consider and 424 equations to solve. An analyst would be faced with a time consuming challenge to solve for all of these equations, which consider all the variables, without a computer program. With a Dell computer with two 2.30GHz processors and 128 GB RAM, the execution time of our model on this small dataset in the GAMS version 24.6.1 with CPLEX 12.0 is 0.156 seconds (GAMS 2016).

Our baseline results for running this dataset in our model returns the missions chosen for fulfillment, which maximize the value of the objective function. The optimal solution for our small data set is the fulfillment of missions M2 through M11, M13, M16 and M20. Since the selections are based on binary choice, a 1 in the GAMS output (not shown) indicates that units are assigned to all mission segments; therefore, the associated mission is assigned full value. Otherwise, partial value is not assigned and as such a zero is assigned to M1, M12, M14, and M15, indicating units are not allocated towards completing those missions. A GAMS report output is in a comma-delimited file easily read by Excel and referred to as the Mission Allocation Report (report in Appendix A). The mission allocation report only provides a partial picture and does not explain why or why not a mission is accomplished. To aid the analyst to answer these questions and other, our model also creates a Unit Inventory Sensitivity Report in Excel.

The Unit Sensitivity Report is especially useful as it shows us the inventory of units throughout the fiscal year as they are used for mission requirements (report in Appendix B). An analyst can easily create a chart from this output (Figure 10), to identify where unit inventory drops during the fiscal year.



Of interest to fulfilling requirements for mission M1, we see that the unit U4 goes to zero inventory in T26 and the unit U6 goes to only two units available in T30. This result implies that an additional unit of U4 may be all that is necessary for M1 to be accomplished.

Figure 10. Small Dataset Unit Inventory Sensitivity Results

As previously mentioned, we observe the top prioritized mission M1, as well as M12, M14, M15, M17, M18 and M19 are unfulfilled in the optimal solution for the base case. With this result in mind, we explore some likely "what-if" questions from stakeholders in the section that follows.

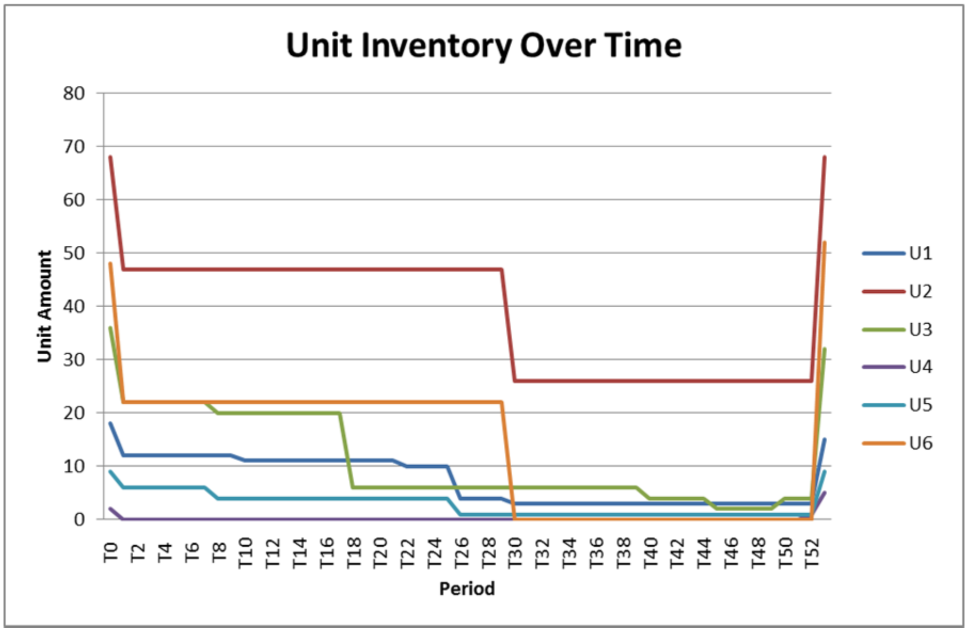
2. Small Dataset What-If Analysis

Many questions are sure to follow as our model chooses not to fulfill the number one priority mission M1. A couple of likely questions from stakeholders would be "Why was the top priority mission not fulfilled" and "What would it take to make that mission happen?"

We can identify why M1 was not fulfilled by forcing its fulfillment and then observing what missions are newly unfulfilled. After rerunning the model with M1 , we see that both missions M2 and M5 are no longer fulfilled. To discover why M1, M2 and M5 cannot all be fulfilled at the same time we look to each mission's unit requirements and our unit inventory sensitivity chart. These missions were fulfilled over M1 in the base results because the combined value of M2 and M5 was greater than the value of M1 alone. This may be attributable to the ordinal ranking of missions, where mission values are only 1 less per rank.

We anticipate stakeholders will want to know what it will take to fulfill the top priority mission M1. It is unlikely that an analyst will be able to adjust mission priority values. We look instead at what extra units it will take to fulfill the M1 requirements. We built our model to output the results of both mission fulfillments, and the individual unit type's inventory as it changes over each period during the fiscal year. We can identify where units fall below the amount required by M1 in the chart built from the unit inventory sensitivity report (Figure 10).

Reviewing the original mission requirements for M1 (Figure 9) and the unit sensitivity report chart (Figure 10), we see that the unit inventory falls short of M1 requirements for U4 in T26 and U6 in T30. To adjust for these deficits we add new units to the inventory in our model for each as follows: 2 new U4 units in period T26, 1 new U4 unit in period T52, 4 new U6 units in T30. To verify that this adjustment fulfills M1 and does not add more units than necessary we rerun the model with the adjustments to our new unit inventory data. The new mission allocation report of our model verifies the fulfillment of M1, and we can see from our new unit sensitivity report chart (Figure 11) that the unit inventory for U4 and U6 are both at zero, meaning that we did not add more units than necessary.



After adding U4 and U6 units to the inventory to fulfill M1, we easily verify that U4 and U6 are both at an inventory of level meaning we added the minimum amount necessary.

Figure 11. Small Dataset Adjusted Unit Sensitivity Results

The process of answering what-if questions like “Why was the top priority mission not fulfilled” and “What would it take to make that mission happen?” takes less than 5 minutes for an analyst using this model. The analyst need only make a few adjustments to the model inputs to answer many what-if questions. The analyst can then competently go back to the stakeholders to tell them why the mission was not chosen for fulfillment. The analyst can also answer what it will take to fulfill the mission in question with a specific time, unit type and amount of unit necessary without detriment to the model’s original optimal solution. This process is easily repeatable for any other missions that are left unfulfilled by the model. With seven of twenty missions unfulfilled in the small dataset an analyst can repeatedly conduct this process to answer the stakeholders questions on all unfulfilled missions in short order. In the current USSOCOM process, there is no equivalent method to answer the same question in a timely manner, especially when considering a large-scale data set as discussed in the next section.

3. Large Dataset Results

We create a larger dataset similar in size and scope to the full classified mission set provided by USSOCOM to test the computational robustness of the model. The large data test set includes 300 missions with 1190 associated mission requirement segments. On average, each mission has about 4 mission requirement segments. The least amount of mission requirement segments a mission has is 2 and the maximum amount is 12. Additionally, there are a total of 90 unit types required for these missions. A typical mission requests an average of 2 different unit types, with a minimum of one unit type requested and a maximum of 5 different unit types requested. The model runtime statistics for this instance is 7,451 single variables in consideration in 6,258 equations. The execution time in GAMS version 24.6.1 using CPLEX 12.0 is still less than a second at 0.733 seconds using a Dell computer with two 2.30GHz processors and 128 GB RAM. This large dataset instance demonstrates that the optimization model should easily handle the computational requirements for the USSOCOM full mission set.

In the large data set allocation report we observe that the top three prioritized missions are not fulfilled, and a total of 76 out of 300 missions are left unfulfilled. The same process from the small data set what-if analysis can be conducted for analyzing why mission are not fulfilled in the large dataset. With our unit inventory sensitivity report and a few minutes per mission an analyst is able to answer all what-if questions on all 76 missions in about a two full days of work. We believe this feat made possible by our optimization model would not even be plausible under the current practices of USSOCOM.

V. RECOMMENDATIONS AND CONCLUSIONS

A. FUTURE WORK

This model should be executed with the classified subset of data provided by USSOCOM with results returned to the sponsor only. USSOCOM can compare the optimized model results with the actual mission allocation they have chosen for fiscal year 2017. Other future work continues in the area of further development of the mission prioritization model and identifying appropriate substation unit types for primary unit types.

Throughout this thesis, we identify some of the shortcomings of having an ordinal mission priority list. For instance, the base result of our small dataset reflects a potential concern of having an ordinal ranked priority list that does not correctly reflect the significance of M1 relative to M2 and the other prioritized missions. USSOCOM is currently working to further develop the mission prioritization list to be non-ordinal. We believe this effort will improve the associated objective function coefficients for this optimization model.

We also recommend that the TSOCS and USSOCOM identify alternative unit types that may be used to fulfill missions. In other words, what unit types are interchangeable or can be substituted for the primary unit type to accomplish a mission's goals, albeit at perhaps a lower mission value or with some penalty? By identifying substitutable units, the resulting total unit-to-mission assignment value will be much greater.

B. CONCLUSION

We formulate a model for the optimal allocation of units to missions, where the prioritized mission list informs our objective function coefficients. We create easy to read output reports that can readily be interpreted by analysts and non-analysts alike. The Mission Allocation Report displays what missions are fulfilled by the optimal solution of our model in an easy to read excel format. The Unit Inventory Sensitivity Report is used to create a chart to show the inventory of any given unit during each period of the fiscal year. We show that the structure of our model combined with these reports help the analyst pinpoint where to look to quickly answer stakeholder's what-if questions.

We run the model on a small dataset to portray the complexity of the problem for even a few missions and to exercise the model to show how we readily analyze the results. With the current process at USSOCOM, a stakeholder would likely seek to fulfill the top priority mission, without readily knowing the consequences on other missions. With our model, it is now possible to easily identify conflicting mission requirements to see what missions are left short if the top priority mission is forced to be fulfilled. Our model enables decision makers and stakeholders to make more informed decisions, i.e., whether to fulfill one high priority mission or to fulfill several other missions with the same resources. Our model also enables an analyst to inform a stakeholder on where resources fall short in fulfilling missions. The decision maker or other stakeholders can then take that information to obtain the resources necessary to fulfill the missions, either by requesting additional resources or possibly by decreasing reset timelines to make more resources available.

Additionally, we ran our model on a large data set and showed that it is easily capable of solving for the full USSOCOM mission set in under a second. Finally, we explain how the same techniques used to analyze the small dataset results may also be applied to the large data results and thus, USSOCOM's full mission set. Our end result and the contribution of this thesis is a model that provides analysts with a powerful optimization tool that enables them to conduct timely analysis to provide stakeholders with better insight on how to optimally allocate units to missions.

APPENDIX A. MISSION ALLOCATION REPORT

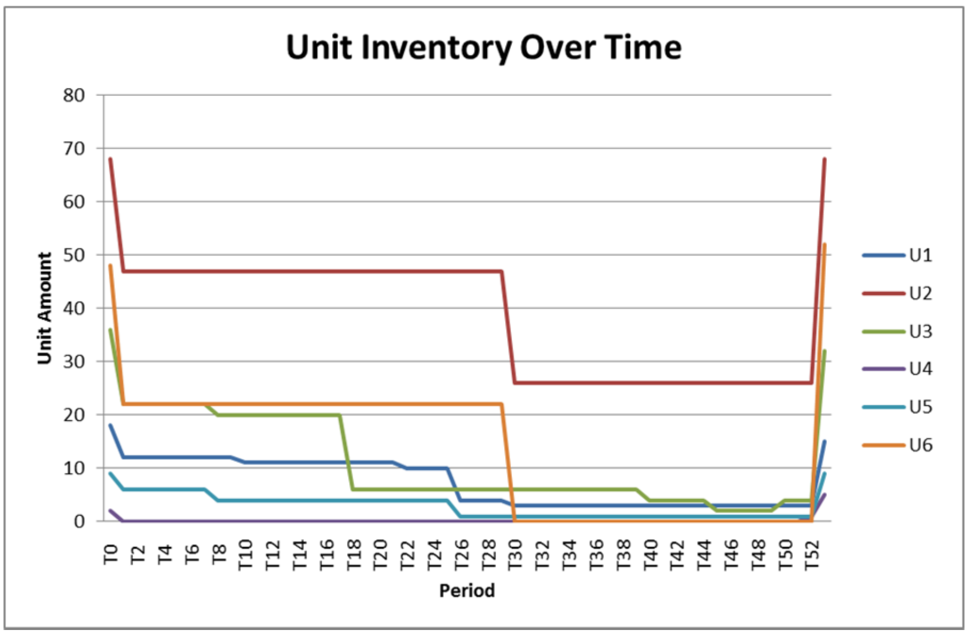
The mission allocation report displays missions filled by the model in an easy to read Excel format. As an example, the content of the mission allocation report for the small dataset is displayed below. It follows that any missions unfulfilled are not listed in this report. This report also displays fulfillment of mission by segments, the content of which is shown on the following page.

Missions Filled
M2
M3
M4
M5
M6
M7
M8
M9
M10
M11
M13
M16
M20

Missions Filled by Section				
Mission	Section	Unit	Value	Number of Units
M2	A	U1	19	2
M2	B	U1	19	2
M2	C	U1	19	2
M2	D	U4	19	1
M2	E	U4	19	1
M2	F	U4	19	1
M2	G	U6	19	5
M2	H	U6	19	5
M3	A	U5	18	1
M3	B	U5	18	1
M3	C	U3	18	4
M3	C	U5	18	1
M3	D	U3	18	4
M3	E	U3	18	4
M3	F	U3	18	4
M4	A	U3	17	2
M4	B	U5	17	2
M5	A	U5	16	2
M5	B	U5	16	2
M5	C	U5	16	2
M5	D	U3	16	2
M5	E	U3	16	2
M5	F	U3	16	2
M5	G	U3	16	2
M6	A	U6	15	2
M6	B	U6	15	2
M6	C	U2	15	7
M6	D	U2	15	7
M7	A	U2	14	3
M7	B	U2	14	3
M8	A	U2	13	3
M8	B	U2	13	3
M9	A	U2	12	4
M9	B	U2	12	4
M10	A	U2	11	4
M10	B	U2	11	4
M11	A	U3	10	5
M11	B	U3	10	5
M11	C	U3	10	5
M11	D	U3	10	5
M13	A	U6	8	4
M13	B	U6	8	4
M16	A	U6	5	4
M16	B	U6	5	4
M20	A	U6	1	8
M20	B	U6	1	8

APPENDIX B. UNIT INVENTORY SENSITIVITY REPORT

The unit sensitivity report is an easy to read Excel file, which includes model output for the inventory of units, new units, and removed units over each time period. The content of the unit sensitivity report for the small dataset is displayed over the next several pages. An analyst can review this report to see where unit inventory is limited, and then conduct analysis on where to add resources to complete missions and answer stakeholder “what-if” questions. An analyst can also use this report to create a chart, similar to the one from the small dataset unit inventory over time below, to create a visual aid for identifying limited resources.



Inventory by unit over time

	Unit:					
Period:	U1	U2	U3	U4	U5	U6
T0	18	68	36	2	9	48
T1	16	47	25	1	6	25
T2	16	47	25	1	6	25
T3	16	47	25	1	6	25
T4	16	47	25	1	6	25
T5	16	47	25	1	6	25
T6	16	47	25	1	6	25
T7	16	47	25	1	6	25
T8	16	47	23	1	4	25
T9	16	47	23	1	4	25
T10	15	47	23	1	4	25
T11	15	47	23	1	4	25
T12	15	47	23	1	4	25
T13	15	47	23	1	4	25
T14	15	47	23	1	4	25
T15	15	47	23	1	4	25
T16	15	47	23	1	4	25
T17	15	47	23	1	4	25
T18	15	47	12	1	4	25
T19	15	47	12	1	4	25
T20	15	47	12	1	4	25
T21	15	47	12	1	4	25
T22	14	47	12	1	4	25
T23	14	47	12	1	4	25
T24	14	47	12	1	4	25
T25	14	47	12	1	4	25
T26	12	47	12	0	1	25
T27	12	47	12	0	1	25
T28	12	47	12	0	1	25
T29	12	47	12	0	1	25
T30	11	26	12	0	1	2
T31	11	26	12	0	1	2
T32	11	26	12	0	1	2
T33	11	26	12	0	1	2
T34	11	26	12	0	1	2
T35	11	26	12	0	1	2
T36	11	26	12	0	1	2
T37	11	26	12	0	1	2
T38	11	26	12	0	1	2
T39	11	26	12	0	1	2
T40	11	26	10	0	1	2
T41	11	26	10	0	1	2
T42	11	26	10	0	1	2
T43	11	26	10	0	1	2
T44	11	26	10	0	1	2
T45	11	26	8	0	1	2
T46	11	26	8	0	1	2
T47	11	26	8	0	1	2
T48	11	26	8	0	1	2
T49	11	26	8	0	1	2
T50	11	26	10	0	1	2
T51	11	26	10	0	1	2
T52	11	26	10	0	1	2
T53	15	68	32	2	9	48

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